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Structuur van Computerprogramma's 2

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Chapter 4 - Built-in Type Constructors

Structuur van Computerprogramma's 2

Built-in Type Constructors

Overview of Concepts

- user-defined / built-in type constructors
- constant objects, constant reference parameters, constant member functions, constant data members, constant pointers
- physically / logically constant, const_cast operator, mutable qualifier
- pointers (*), null pointers (0)
- dereference operator (*), address operator (&)
- handles
- reference type
- this-pointer
- arrays, array size, array initialization
- pointer arithmetic
- c-style strings
- dangling pointers, memory leaks
- explicit memory management, memory allocation / deallocation, delete, new

Type Constructors

C++ supports

- **built-in type constructors:**
  - `&` for references
  - `const` for constants
  - `*` for pointers
  - `[ ]` for arrays
- **user-defined type constructors:**
  - templates (later)

A **type constructor** is a compile-time function *construct* that, given a type *t*, returns another type *construct(t)*

e.g., **&** is a type constructor $reference : T \longrightarrow T\&$

Constants

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Constant Objects

```
const NameOfType Variable(InitialValue);
```

The **compiler will ensure** that (after construction) the object referred to by `Variable`, will **not be changed through this variable**

```
const int x(4);
x = 5; // error

int y(6);
const int& z(y);
y = 5; // ok
z = 7; // error, why?

const int u(7);
int& v(u); // what will happen?
```

assignment
=
change

construction (initialization)
≠
change

```
../main.cpp:34: error: invalid initialization of reference
of type 'int&' from expression of type 'const int'
```

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Constant Reference Parameters

- Indicates a promise by a function not to change a parameter
  - The compiler checks if this promise is kept

```
class Rational {
public:
   Rational(int num, int denom) :
      num_(num), denom_(denom) {
      if (denom == 0)
         abort();
   }
   Rational multiply(const Rational& r) {
      return Rational(num_ * r.num_, denom_ * r.denom_);
   }
private:
   int num_;
   int denom_; // must not be 0!
};
```

Which checks should the compiler perform to ensure that the const promise is kept?

Constant Members (data + functions)

```
class Rational {
public:
   Rational(int num, int denom) :
      num_(num), denom_(denom) { // ...
   }
   bool isnegative() {   return denom() * num() < 0; }
   Rational multiply(const Rational& r) {
      return Rational(num_ * r.num_, denom_ * r.denom_);
   }
// ...
private:
// silly because operations won't work,
// but illustrates that data members can be const
   const int num_;
   const int denom_; // must not be 0!
};
```

How to ensure that a member function doesn't change the data members of **the target** object?

Constant members can only be initialized in the initialization list of a constructor (not in the body)

```
Rational r1(1, 2);
const Rational r2(2, 3);
r1.isnegative();
r1.multiply(r2);
```

```
r2.isnegative();
r2.multiply(r1);
```

Will this work?

```
../main.cpp:37: error:
passing 'const Rational' as 'this' argument of 'bool
Rational::isnegative()'
```

```
../main.cpp:38: error:
passing 'const Rational' as 'this' argument of 'Rational
Rational::multiply(const Rational&)' discards qualifiers
```

Constant Members: Solution

A (physically) **constant member function** promises **not to modify** the target object (i.e. everything accessible via *this)

```
class Rational {
public:
   Rational(int num, int denom) :
      num_(num), denom_(denom) { // ...
   }

   bool isnegative() const {return denom() * num() < 0; }

   Rational multiply(const Rational& r) const {
      return Rational(num_ * r.num_, denom_ * r.denom_);
   }
// ...
private:
   const int num_;
   const int denom_; // must not be 0!
};
```

constant member function

Will only work if **denom()** and **num()** used in **isnegative()** are also declared as constant member functions !

```
Rational r1(1, 2);
const Rational r2(2, 3);
r2.multiply(r1);
```

Will this work?

Logically Constant vs Physically Constant (1)

```
class Rational { //ADT representing rational numbers
public:
    Rational(int num = 0, int denom = 1) :
        numerator_(num), denominator_(denom) {
        assert(denominator_ != 0);
    }
    Rational inverse() const { return Rational(denom(), num()); }
    bool isnegative()  const {return denom() * num() < 0; }

    void simplify() {
        int g(gcd(num(), denom()));
        numerator_ /= g;
        denominator_ /= g;
    }

    int num()   const { return numerator_; }
    int denom() const { return denominator_; }
    friend istream& // reads 2/3 as well as 4, the latter is understood as 4/1
          operator>>(istream&, const Rational&);

private:
    int numerator_;
    int denominator_; // must not be 0!
};
```

const member functions

what to do with `simplify()`? (see next slide)

`simplify()` is a **logically constant** function, whereas `inverse()`, `isnegative()`, `num()`, `denom()` are **physically constant** functions

Logically Constant vs Physically Constant (2)

calling this discards the const requirement of r, since simplify is not physically constant

```
ostream& operator<<(ostream& os, const Rational& r) {
    r.simplify();
    os << (r.isnegative() ? "-" : " ") << abs(r.num());
    if (abs(r.denom()) != 1)
        os << "/" << abs(r.denom());
    return os;
}
```

Will this work?

Making `simplify()` a constant member function is not an option since it needs to "modify" the data members

Options:

- Don't pass r as a constant reference but by value, or
- Use the const_cast operator
  - to "cast away" the constness of r

    ```
    const_cast<NonConstantType>(Expression)
    ```

    ```
    const_cast<Rational&>(r).simplify()
    ```

  - or to turn `Rational::simplify` into a constant member function, and use

    ```
    const_cast<Rational*>(this)->numerator_ /= g; // see later - pointers
    ```

Don't use it to circumvene the physical constantness if you cannot motivate that it is actually logically constant!

- Use the `mutable` qualifier to a data member(see book p. 88)

Overloading and `const`

The usual matching rules apply (**`const T`** is a "normal" type)

```
int f(const int& i) {
   return i;
}

int f(int& i) {
   return ++i;
}
```

```
int main() {
   const int c(5);
   int d(5);

   // an exact match, calls f(const int&); prints 5
   std::cout << f(c) << std::endl;

   // two matches, but calls f(int&) which is the closest; prints 6
   std::cout << f(d) << std::endl;
}
```

Conversion from non-const to const

```
int f(const int& i) {
  return i;
}

int main() {
  int d(5);

  // calls f(const int&);
  // after implicit ‘conversion’ of int& to const int&
  std::cout << f(d) << std::endl;
}
```

This is allowed because you do not break any programmer-imposed restrictions:

- non-const implies that you are allowed (but not forced) to change the value.
- const implies that you are never allowed to change its value.

Pointers

Pointers

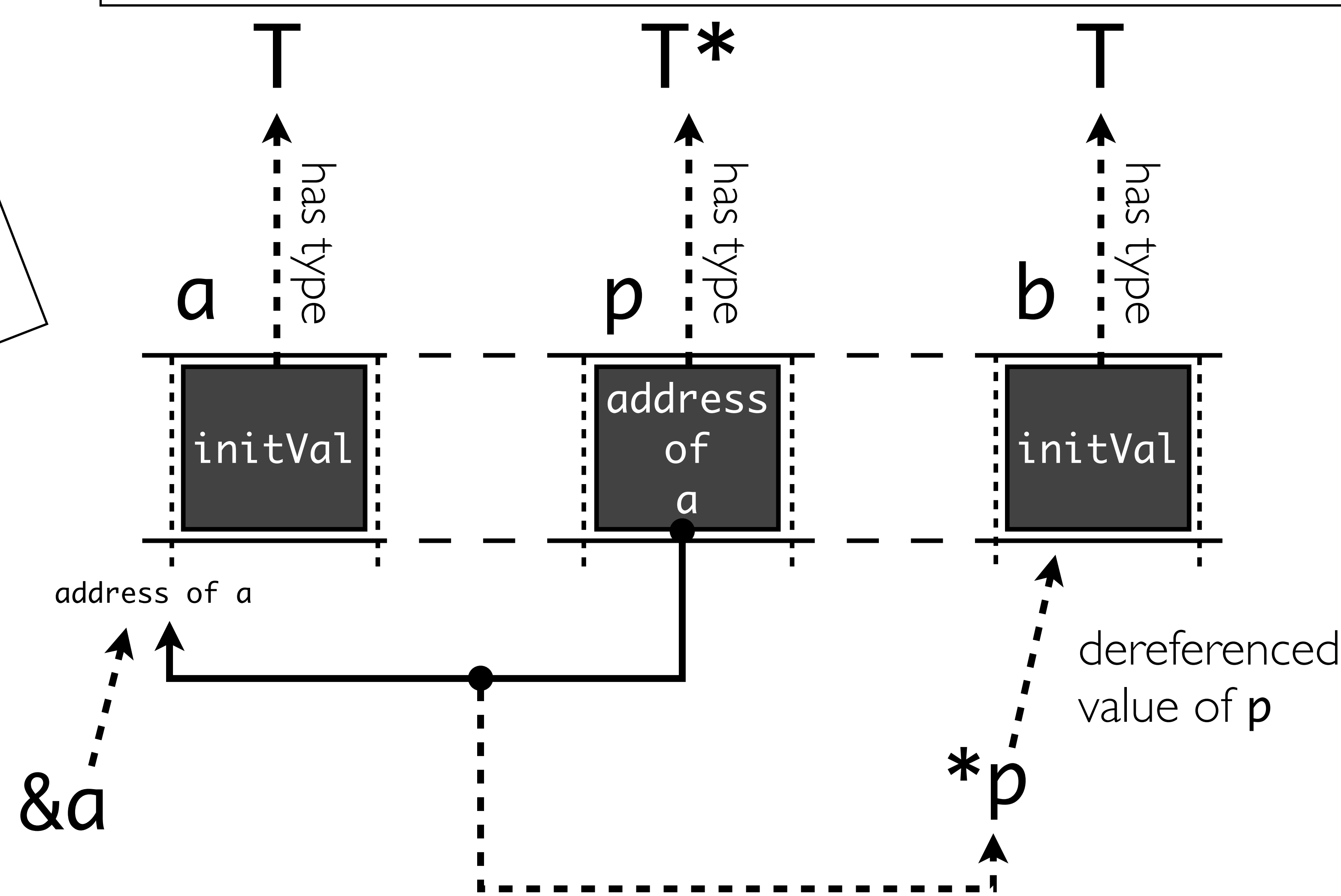
A **pointer** is an object whose value is the address of another object

```
NameOfType* NameOfVariable(InitialValue);
```

```
T   a(initVal);
T*  p(&a);
T   b(*p);
```

- `T a(initVal);` — defines a variable **a** of type T and initializes it with `initVal`
- `T* p(&a);` — defines a variable p of type T* (a pointer to T) and initializes it with the address (& **address operator**) of a
- `T b(*p);` — defines a variable b of type T and initializes it with the value (* **dereference operator**) stored at the location to which p points

What's the difference with references? (later)

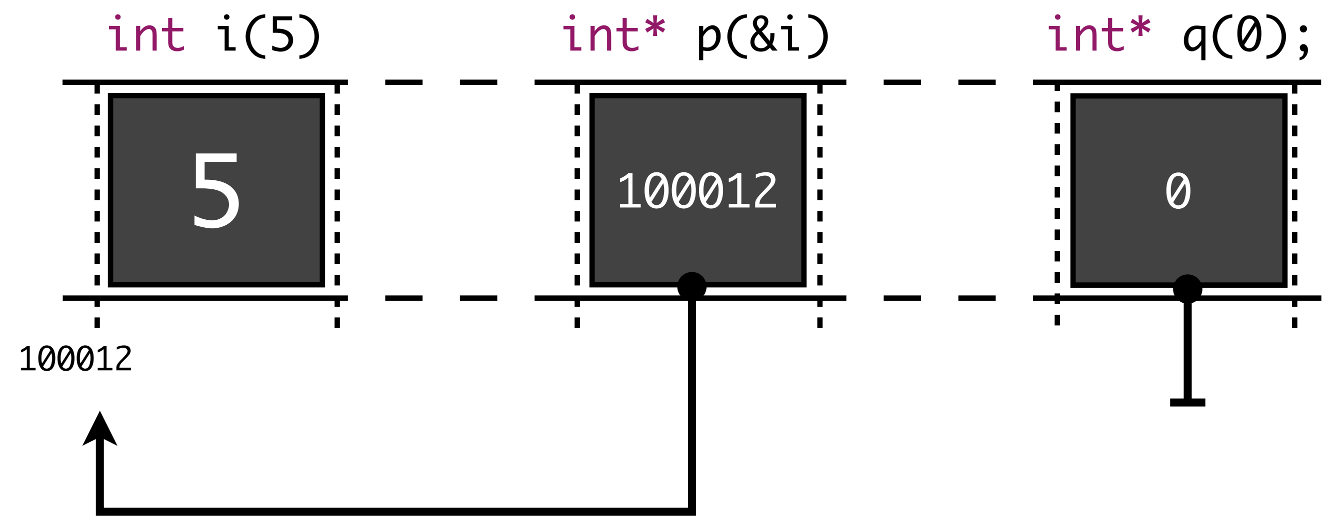


Pointers Example

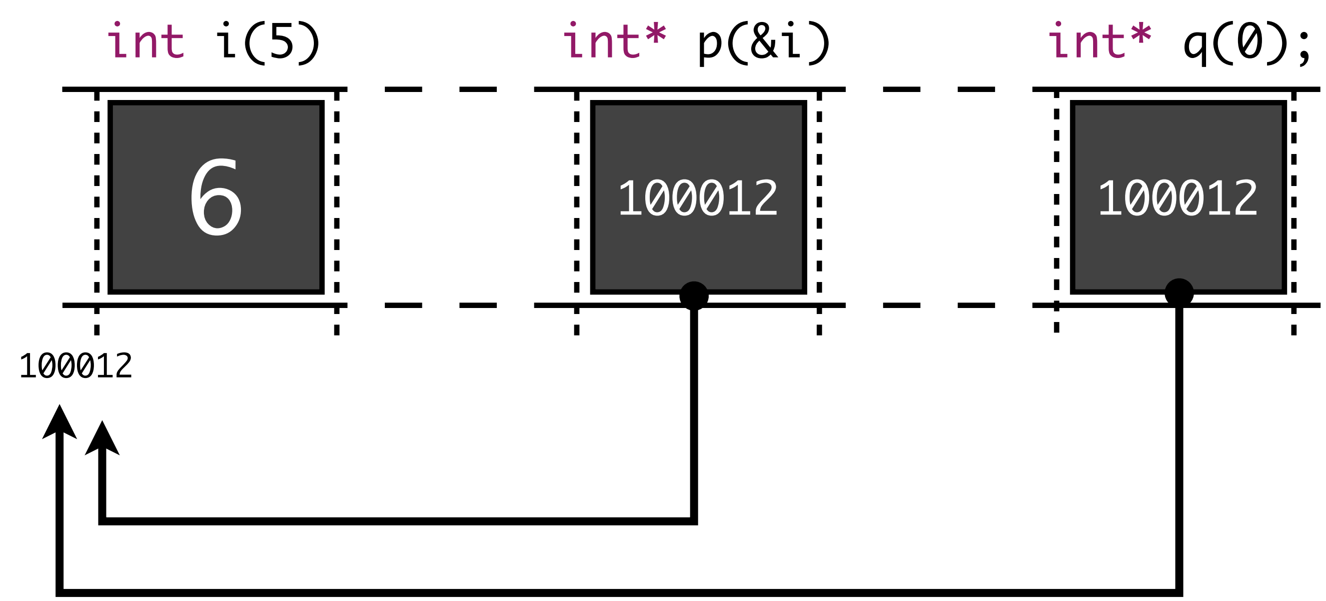
```
int  i(5);
int* p(&i);
int*  q(0);

...

q = p;
*p = 6;
```



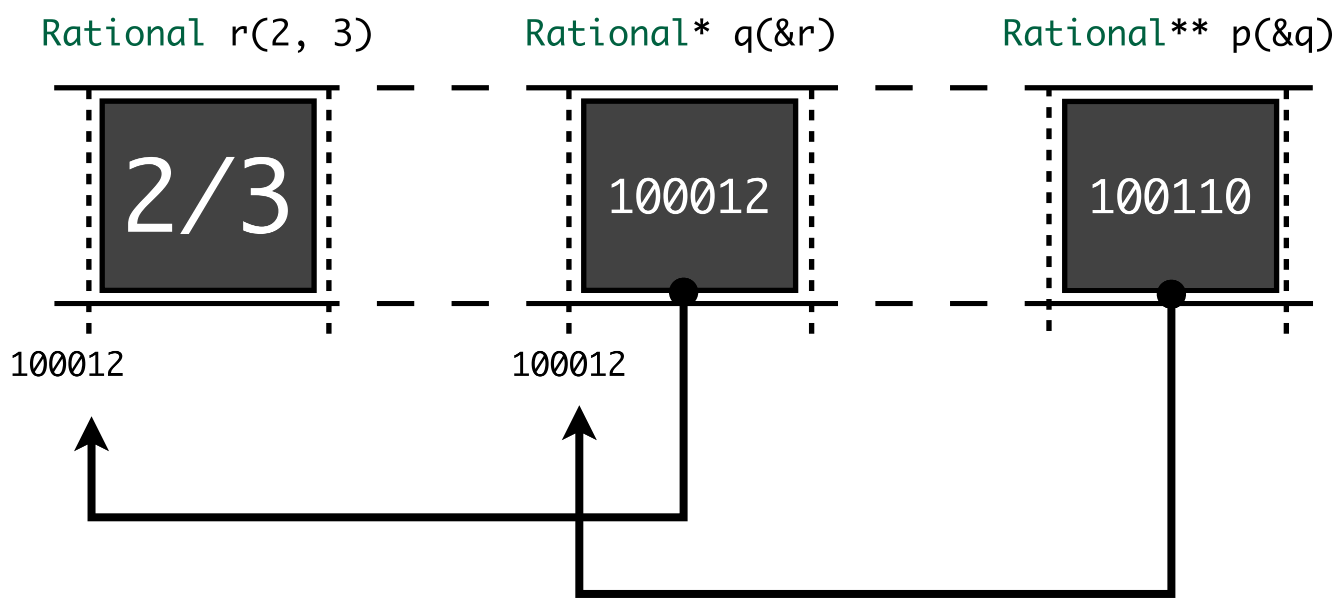
Initializing a pointer with `0` automatically converts it to a **null pointer**



Pointer values can be accessed directly e.g. `cout << p;` prints the address `100012`

Handles (Pointers to Pointers)

```
Rational r(2, 3);
Rational* q(&r);
Rational** p(&q);
```



Why are handles useful?

```
std::cout << **p + *q << "," << r << "," << *q << "," << **p;
```

Member selection from pointers:

`(*Expression).MemberName` ≈ `Expression->MemberName`

```
std::cout << q->add(*q); // short for (*q).add(*q)
```

Pointers as Alternative for References (1)

```
#include  <iostream>

void
swap_p(int* px, int* py) {
   int tmp(*px);
   // copy contents of what py points to
   // to area that px points to
   *px = *py;
   *py = tmp;
}

void
swap_r(int& x, int& y) {
   int tmp(x);
   // copy contents of what y refers to
   // to area that x refers to
   x = y;
   y = tmp;
}
```

Using pointers to "simulate" call-by-address

Pointers as Alternative for References (2)

```
int
main() {
   int a(5);
   int b(6);

   swap_p(&a, &b); // pass pointers to a, b
   std::cout << a << ", " << b << std::endl; // prints 6, 5

   swap_r(a, b);
   std::cout << a << ", " << b << std::endl; // prints 5, 6
}
```

What are the (dis)advantages of using pointers instead of references?

- Parameters need to be explicitly dereferenced inside the function body
- If a parameter of reference type is passed, then it must always supply a valid (reference) to an object (null is not allowed)
    - Check in the function body whether a pointer points to null !
- Pointers allow for passing array parameters (see later)

Pointers and `const`

Forbidding modification of an object "through" a pointer:

```
int i(6);
const int* p(&i);
*p = 5; // error
```

Forbidding modification of the pointer itself:

```
int j(4);
int* const q(&i); // q is a constant pointer to i
*q = 5;           // no problem: you can modify *q
q = &j;           // error: you cannot modify q
```

Forbidding both:

```
// constant pointer to constant integer
const int* const pc(&i);
```

Pointers versus References (Revisited)

```
int i(3);
int& r(i);        // reference must always be initialized
int* const p(&i); // const used to make pointer “immutable”
```

A reference is like a constant pointer where dereferencing is automatic

```
*p = 5; r = 5; // same effect
int j;  // Test “immutability” of our reference and pointer
p = &j; // ERROR: it is also impossible to make r refer to j
```

A pointer can however contain more information (NULL or not)

```
int f(List* l); // l may be 0, i.e. not point anywhere
int f(List& l); // l ALWAYS refers to an existing List object
```

The `this` Pointer

```
class T {
   ReturnType f(ParameterList) {
      T* const this(PtrToTargetObject);
      // ...
   }

   ReturnType f(ParameterList) const {
      const T* const this(PtrToTargetObject);
      // ...
   }
}
```

See the earlier discussion of constant vs non-constant member functions !

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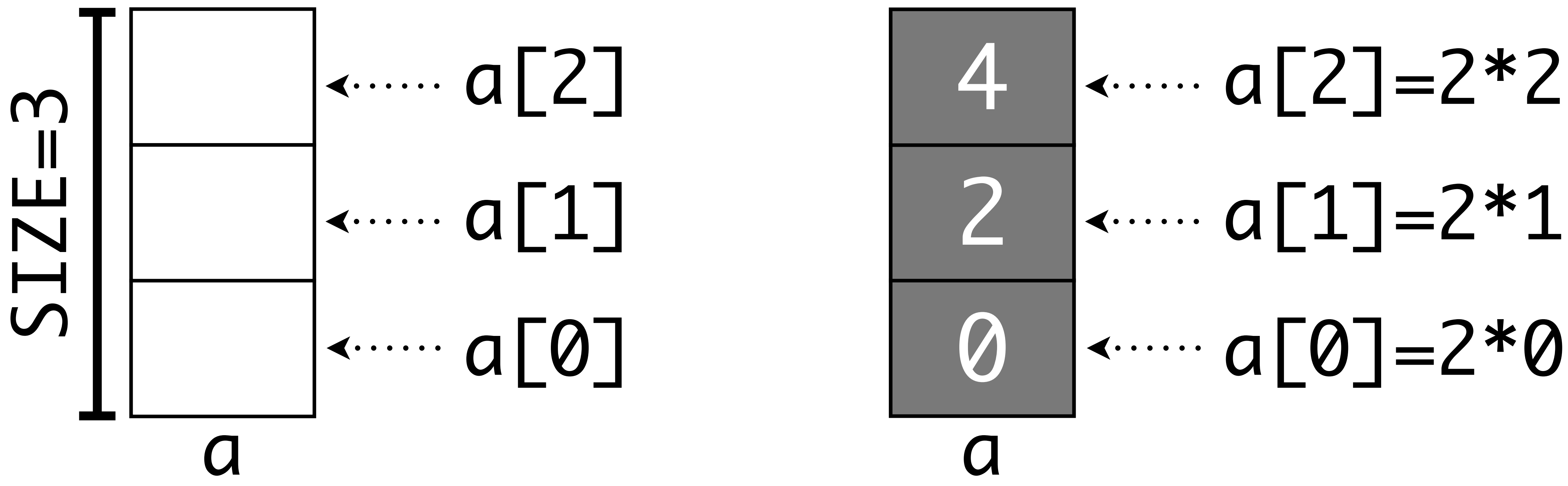
The `this` Pointer: Example of Assignment Operator

```
// should return reference to target object
// in order to support x = y = z;

Rational&
Rational::operator=(const Rational& r) {
   num_ = r.num();
   denom_ = r.denom();
   simplify();
   return *this; // return reference to target object
}
```

Arrays

Arrays




```
const int SIZE = 3;
int a[SIZE]; // array of 3 int objects
             // array indices start from 0 to SIZE-1

for (unsigned int i=0;(i<SIZE);++i)
      a[i] = 2*i;

for (unsigned int i=0;(i<SIZE);++i) // will print 0 2 4
      std::cout << a[i] << " ";
```

Example: Bubble Sort an Array of Strings - Swap

```
#include <iostream>
#include <string>

void swap(std::string& x, std::string& y) {
   std::string tmp(x);
   x = y;
   y = tmp;
}
```

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Example: Bubble Sort an Array of Strings - Sort

```
const int MAX_WORDS = 10;
std::string words[MAX_WORDS];

int main() {
   // read 10 strings from stdin and bubble-sort them
   for (unsigned int i = 0; (i < MAX_WORDS); ++i)
      std::cin >> words[i];

   for (unsigned int size = MAX_WORDS - 1; (size > 0); --size)
      // find largest element in 0..size range and
      // store it at index size
      for (unsigned int i = 0; (i < size); ++i)
         if (words[i + 1] < words[i])
            swap(words[i + 1], words[i]);

   // print the sorted strings
   for (unsigned int i = 0; (i < MAX_WORDS); ++i)
      std::cout << words[i] << " ";
}
```

Initializing Arrays and Size Calculation

```
#include  <iostream>

// compiler can figure out how large the array should be
float vat_rates[] = { 0, 6, 20.5 };

int main() {
   // how to find the number of elements in vat_rates?
   unsigned int size(sizeof(vat_rates) / sizeof(float));

   const char message[] = "VAT rates"; // special case

   std::cout << message;

   for (unsigned int i = 0; (i < size); ++i)
      std::cout << " " << vat_rates[i];

   std::cout << std::endl;
}
```

Initializing Arrays with Default ctor

Arrays of class objects are initialized using the default constructor (without arguments)

```
class Rational {
public:
   Rational(int num = 0, int denom = 1) :
      num_(num), denom_(denom) { }
   // ...
private:
   int num_;
   int denom_;
};

// calls Rational::Rational() on each element
Rational rationals[3];

// constructors can be used in the initialization
Rational more_rationals[] = { Rational(1, 2), Rational(1, 3) };
```

Passing Arrays as Parameters

No size !

Pass the size as an extra argument

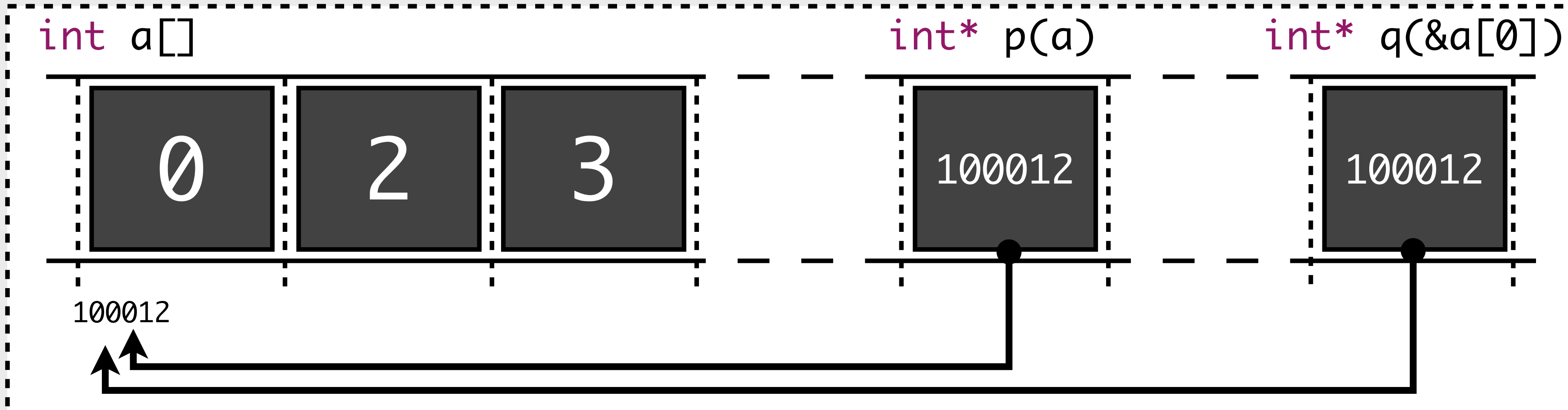
```
int sum(int a[], unsigned int size) {
   int total(0);

   for (unsigned int i = 0; i < size; ++i)
      total += a[i];

   return total;
}

int main() {
   int numbers[] = { 1, 2, 3, 4, 5 };

   std::cout << sum(numbers, sizeof(numbers) / sizeof(int)) << std::endl;
}
```

Can you calculate the size in the body of sum?

- **Arrays are passed by reference**
- The compiler doesn't care about the size of the array
    - The programmer should check this ! (why?)

Arrays versus Pointers

A pointer can be made to point to an array and it can also be indexed



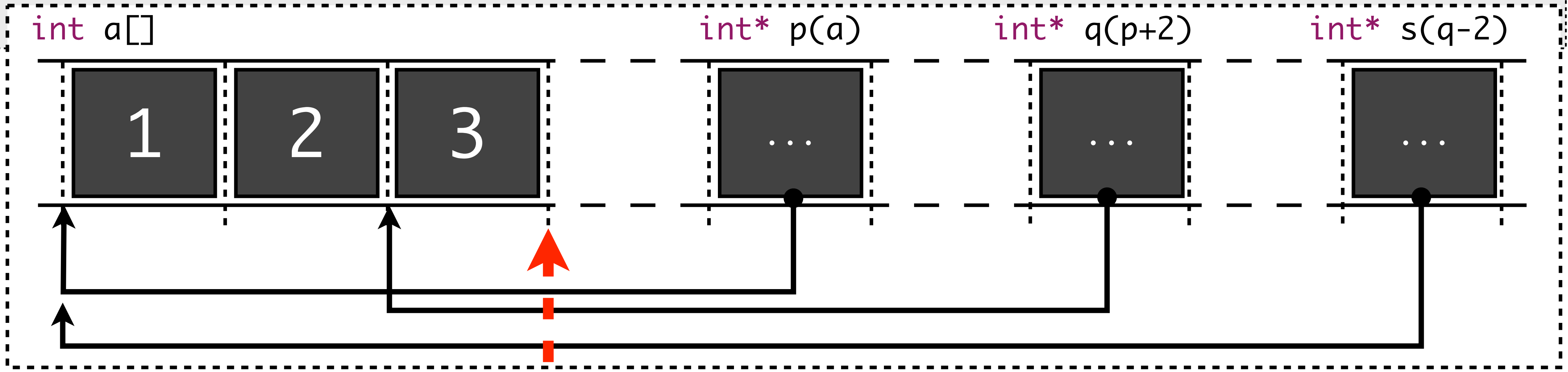

```cpp
#include <iostream>

void f(int x[]) {
   x[0] = 1;
}

int main() {
   int a[] = { 0, 2, 3 };
   int* p(a);
   int* q(&a[0]); // exactly the same as p (i.e. the address of a[0])

   // passing a pointer or an array to f() is the same
   f(p);
   // printing: 1, 1 \newline
   std::cout << *p << ", " << a[0] << std::endl;
   // printing: 1, 1 \newline 2, 2 \newline 3, 3 \newline
   for (unsigned int i = 0; (i < sizeof(a) / sizeof(int)); ++i)
      std::cout << p[i] << ", " << a[i] << std::endl;
}
```

Pointer Arithmetic

Pointers can be assigned, integers can be added to pointers, integers can be subtracted from pointers

```
int a[] = { 1, 2, 3 };

int main() {
   int* p(a);
   int* q(p + 2);
   int* s(q - 2);

   for (unsigned int i = 0; (i < 3); ++i)
      std::cout << *p++ << "\n";

   std::cout << q - p << std::endl;
}
```

What is the output?



new p **after executing the** for **loop !**

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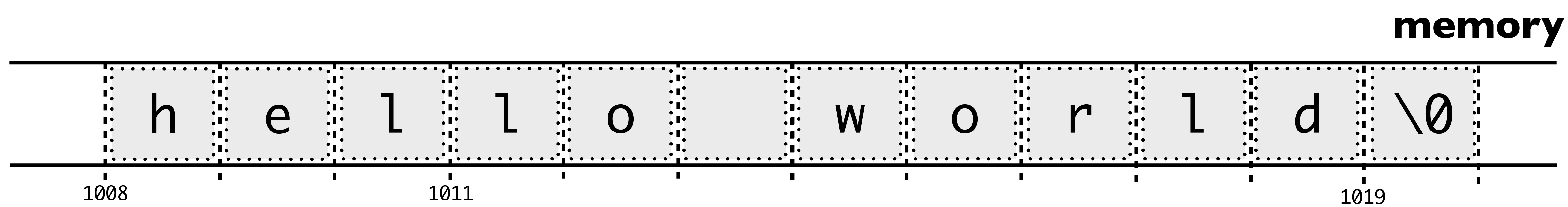
Primitive Types and C-Style Strings (Remember)

- String literals can be represented by using `const char*`
  - These are **C-style** strings, in C++ one can use the `String` container



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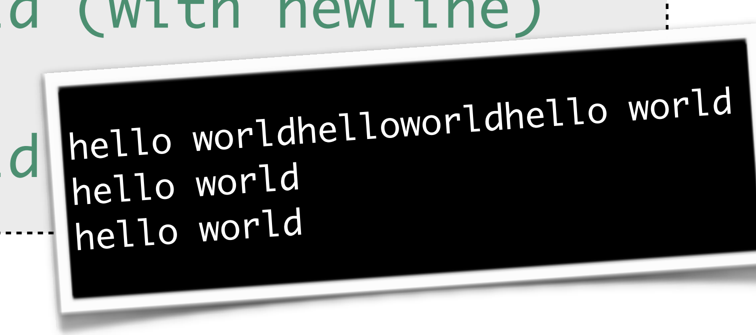
const char*

"hello world" returns a pointer (*) to an array of constant characters, which is automatically closed off with a null character \0

```
std::ostream& operator<<(std::ostream&, const char*);
const char* hi("hello world");

std::cout << "hello world";              // hello world
std::cout << "hello" "world";            // helloworld

std::cout << "hello world\n";            // hello world (with newline)
std::cout << "hello world" << std::endl; // hello world (with newline)

std::cout << hi;                         // hello world
```



C-Strings: Example

```
#include <iostream>

void print(std::ostream& os, const char*p) {
   while (*p)
      os << *p++;
   os << std::endl;
}

int main() {
   const char* s("hello world");
   print(std::cout, s);
}
```

Can you explain why it should be a "const" char pointer?

Comparing C-Strings

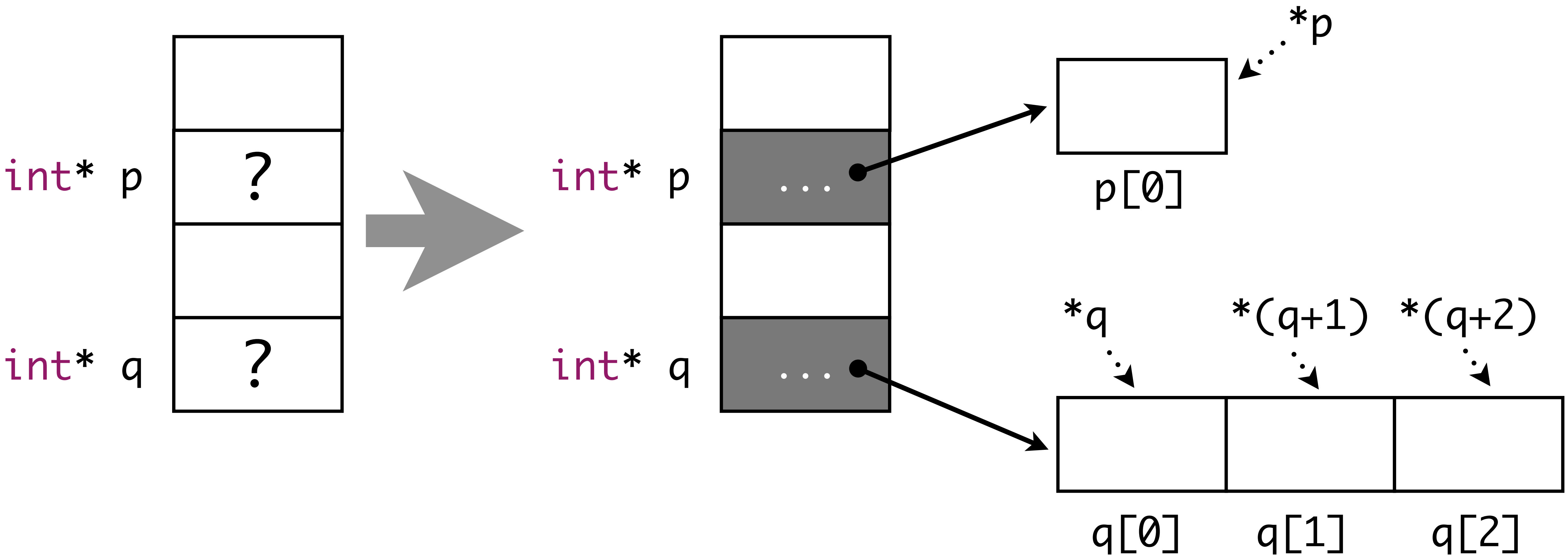
```
#include <iostream>

// returns
// 0  if s1 and s2 are lexicographically equal
// >0 if s1 is lexicographically larger than s2
// <0 if s1 is lexicographically smaller than s2
int strcmp(const char*s1, const char* s2) {
  while ((*s1) && (*s2) && (*s1 == *s2)) {
    ++s1;
    ++s2;
  } // while loop stops if a \0 character is spotted
  return *s1 - *s2; // difference between ascii of letters
}

int main() {
  const char* s1("abc");
  const char* s2("abcde");
  std::cout << strcmp(s1, s2) << std::endl; // prints -100
}
```

Command-line Processing (Remember)

```
#include <iostream>
#include <stdlib.h> // for atoi()

// this program computes the sum of its command line argu
// usage: sum int..

int main(unsigned int argc, char* argv[]) {
   // - argv is an array of pointers to (arrays of) char,
   // one for each argument
   // - argv[0] is the name of the program, i.e.
   // the first word in the command line
   // - argc is the number of arguments
   int sum(0);

   // atoi(const char*) converts a string to an int
   for (unsigned int i = 1; (i < argc); ++i)
      sum += atoi(argv[i]);
   std::cout << sum << std::endl;
}
```

Explicit Memory Management

Explicit Memory Allocation



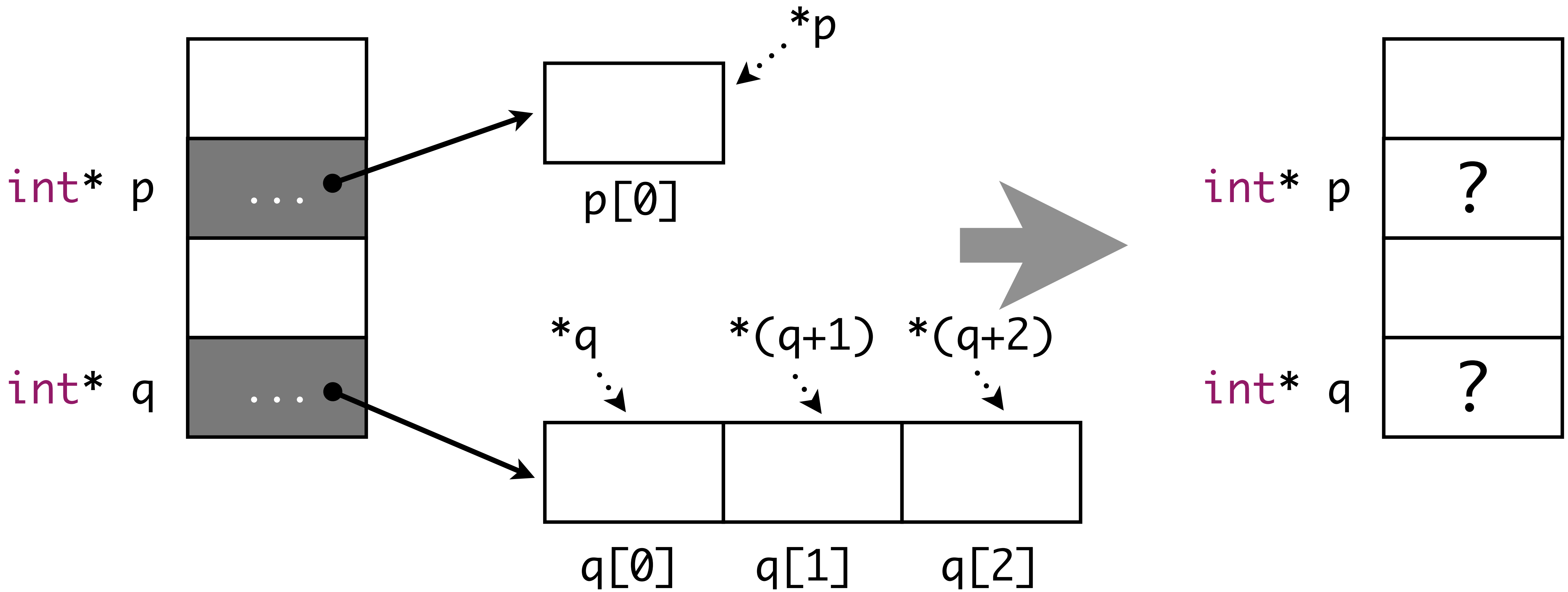

```
int* p; // not initialized
int* q; // not initialized
```

```
p = new int; // allocate memory for 1 new integer
```

```
q = new int[3]; // allocate memory for 3 new integers
```

Explicitly allocated memory does not go away unless the programmer explicitly deallocates it !

Explicit Memory Deallocation



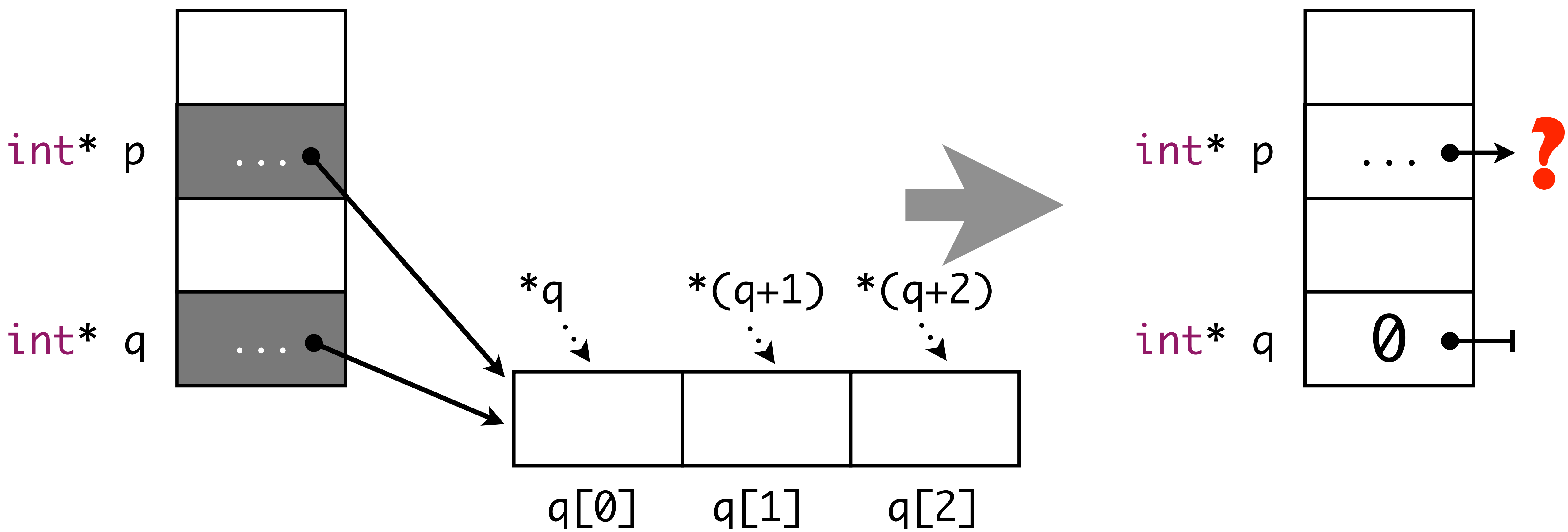

```
int* p;         // not initialized
int* q;         // not initialized
p = new int;    // allocate memory for 1 new integer
q = new int[3]; // allocate memory for 3 new integers
```

```
delete p;       // deallocate memory allocated with new
```

```
delete [] q;    // deallocate memory allocated with new[]
```

After the delete, the pointers are left **"dangling"**

The Dangling Pointer Syndrome




```
int* q(new int[3]);
int* p(q);
```

```
delete [] q;
q = 0; // p is left dangling!
```

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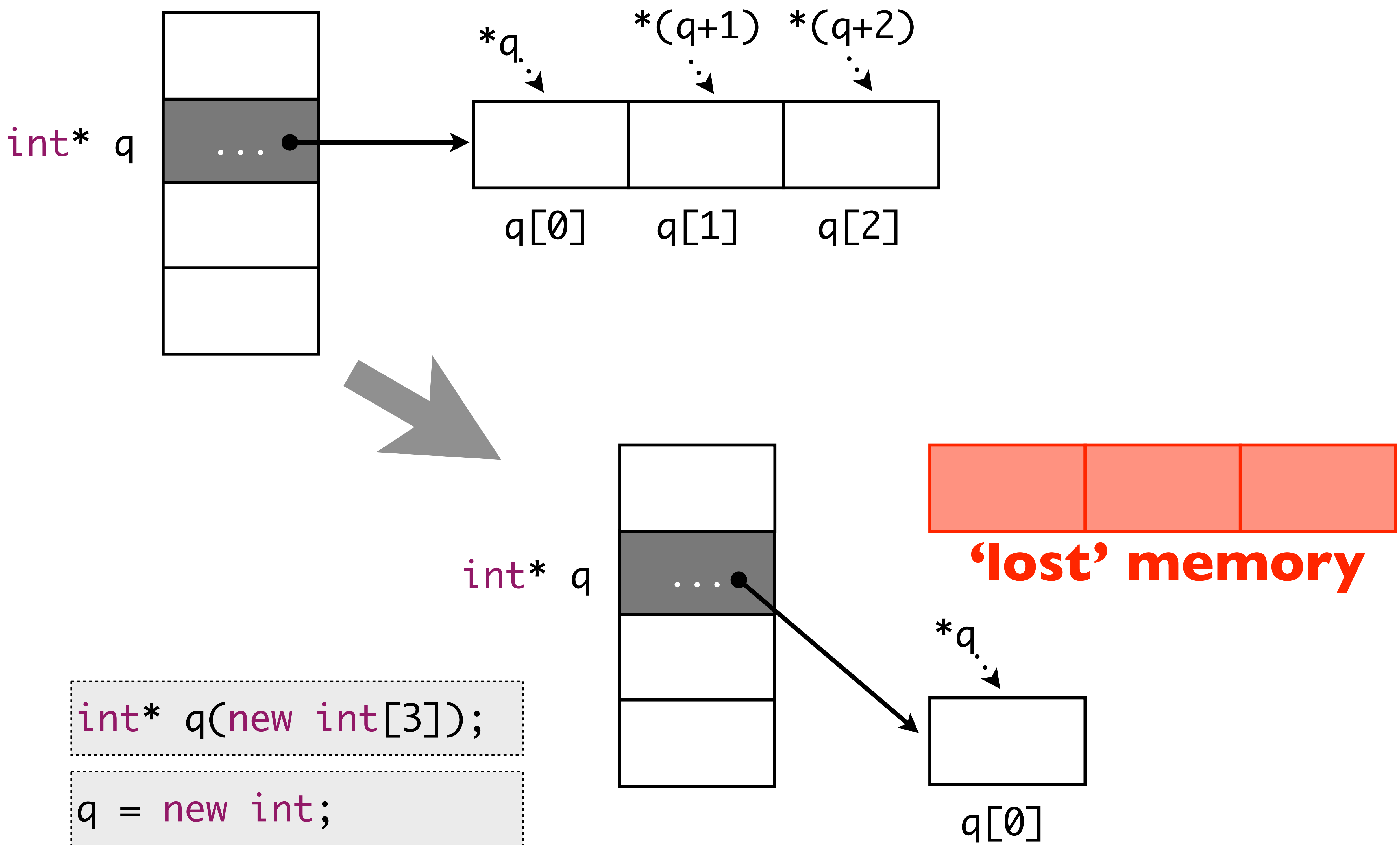
Memory Leaks




```
int* q(new int[3]);
```

```
q = new int;
```

The original allocated memory cannot be referenced anymore !

Object Taxonomy wrt Memory Management

name	how defined	when initialized	when destroyed
static	static var in function body	first call of function	program exit
	static class member	program startup	program exit
	global variable	program startup	program exit
automatic	local var in function body	when definition is executed	exit scope
member	data member of class	just before owner	just after owner
free	using new/delete	determined by programmer	determined by programmer